Plasma Processes, Inc.

Phase I SBIR: Engineered Surfaces for the Lithium Tokamak eXperiment (LTX)

Scott O'Dell

Plasma Processes, Inc.

Richard Majeski and John Timberlake

Princeton Plasma Physics Laboratory

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Motivation

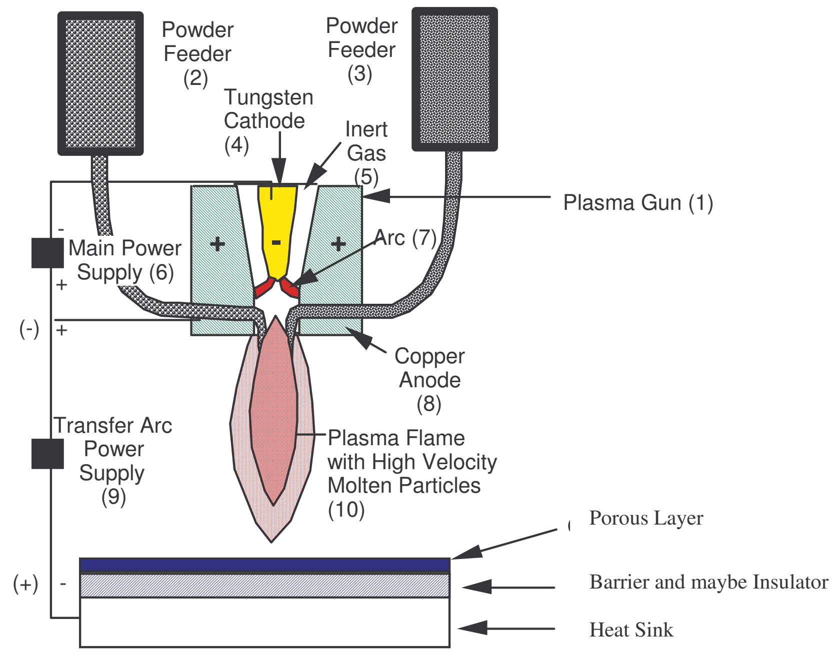
- Reactor studies have identified liquid Li walls as a promising solution to MFE first wall problems
- To date, the use of liquid metal walls has focused on two techniques:
  - Bulk static or fast flowing liquids metals (~1cm thickness)
    - Bulk static liquid Li is only suitable for short-pulse experiments (CDX-U)
    - HHF and long pulse lengths require fast flowing bulk liquid Li to remove heat and limit surface temperature excursions (ALPS and APEX)
    - Centrifugal or electromagnetic forces will be needed to force the liquid lithium to adhere stably to the wall in the presence of plasma disruptions and MHD instabilities
    - The ability to deal with tens or hundreds of liters of liquid metal have made implementation of flowing liquid metals difficult
  - Thin lithium films (several thousand Å thickness)
    - LTX and first Li experiments in NSTX
    - Li film acts as a particle pump and substrate provides thermal mass and acts as a heat sink
    - With actively cooled substrates, the heat handling capacity of the thin Li film approach can be extended to long pulse durations
    - However, thin lithium films can become saturated with hydrogen and form LiH, which has a higher melting temperature than lithium and is not desirable

Alternative Approach

- Thicker lithium film (~0.25mm) embedded in a porous metal matrix atop a high thermal conductivity substrate
  - Thicker film will not saturate for hundreds of discharges
  - Porous layer anchors thick lithium film and enables control of lithium flow
  - High thermal conductivity substrate provides heat removal

Phase I Primary Objectives

- PPI: Develop the fabrication techniques for producing the engineered surfaces
  - Insulating layer to allow J x B driven flow
  - Porous layer with and without intermediate insulating layer
- PPPL: Perform molten lithium tests to determine wetting characteristics and the ability of the engineered surfaces to control lithium flow

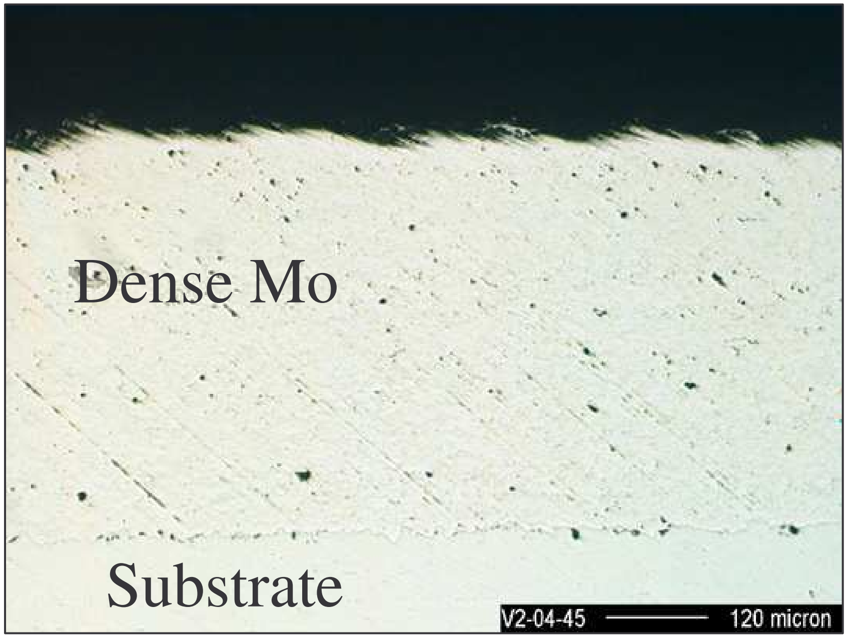


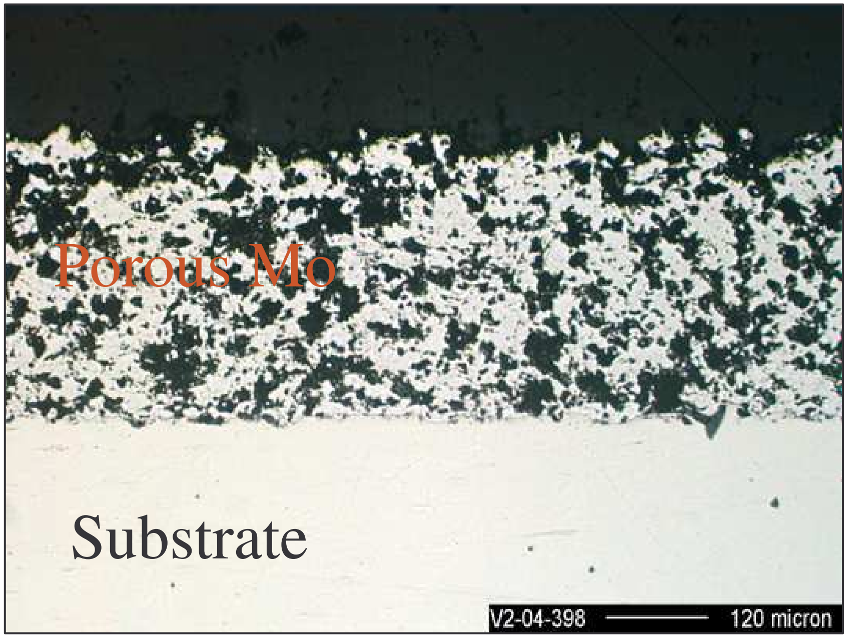
• LTX substrate is a copper alloy with a SS explosion bonded cladding

Porous Layer Development

- Resistance heating wetting tests at PPPL of materials with smooth surfaces.
  - W: ~800ºC
  - SS and molybdenum: >500ºC
- Because SS and molybdenum were wet at slightly lower temperatures, they were chosen for evaluation.
- By adjusting the plasma spray parameters, porous SS and molybdenum deposits were produced.

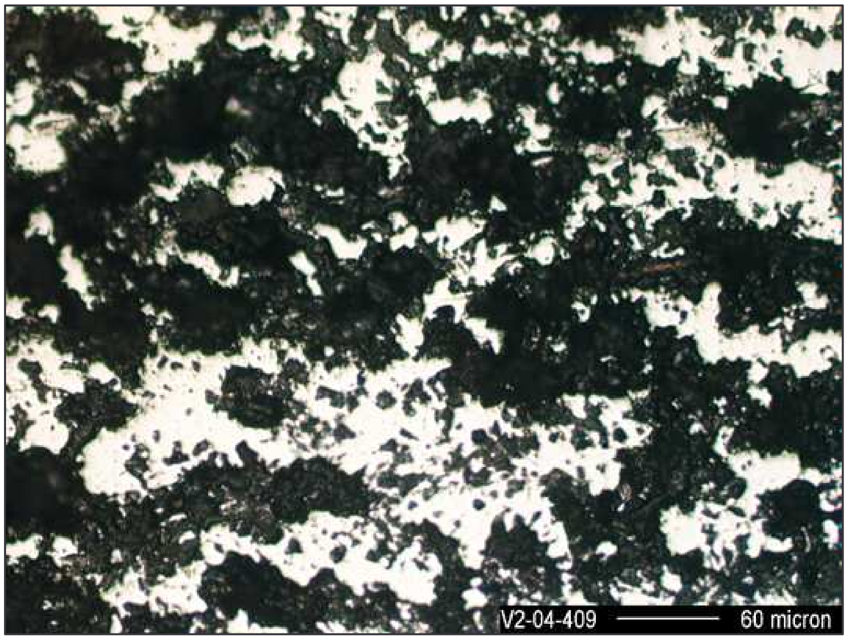
Dense Mo Versus Porous Mo

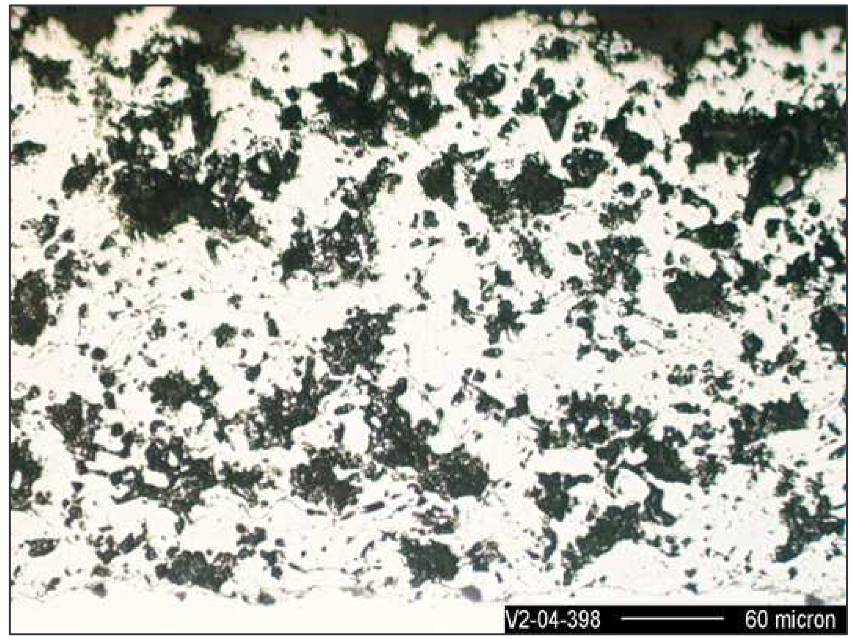




The level of porosity in the porous sample is ~40% as determined by image analysis.

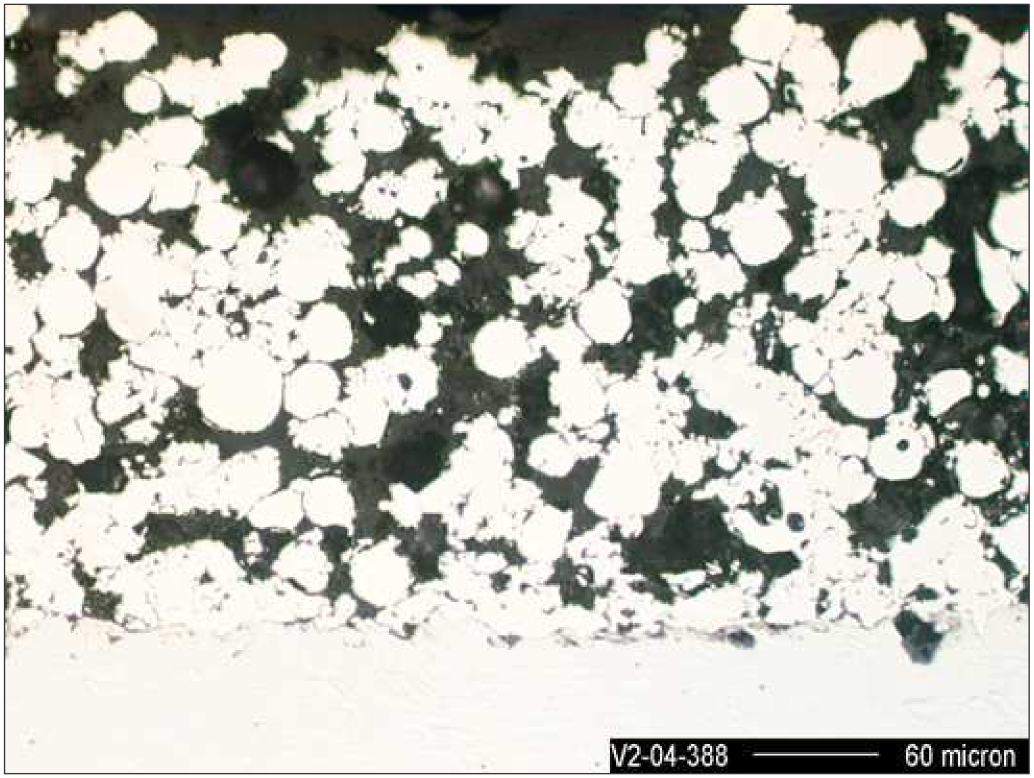
Additional Parameter Adjustments Resulted in ~70% Porous Mo Deposit





- ~70% porous
- ~40% porous

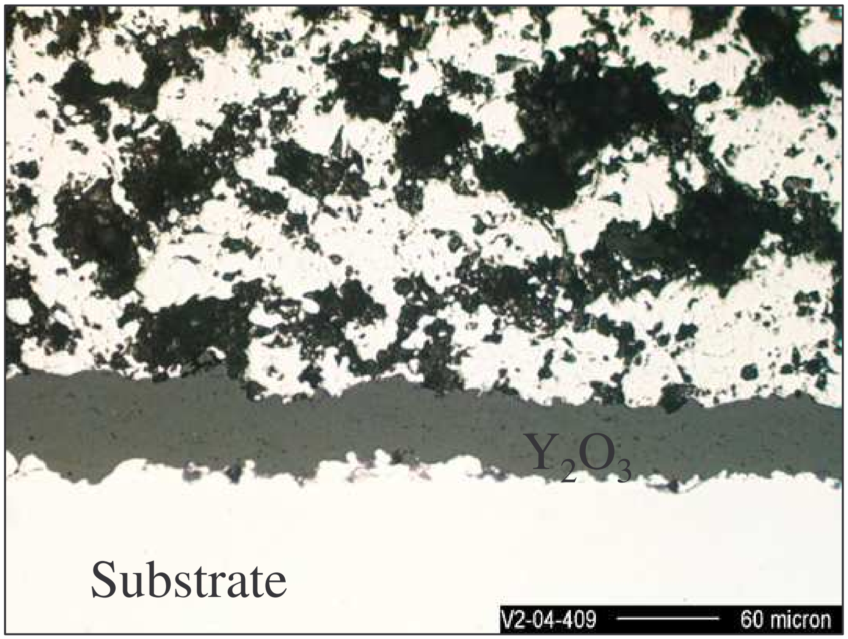
Porous Stainless Steel Deposit

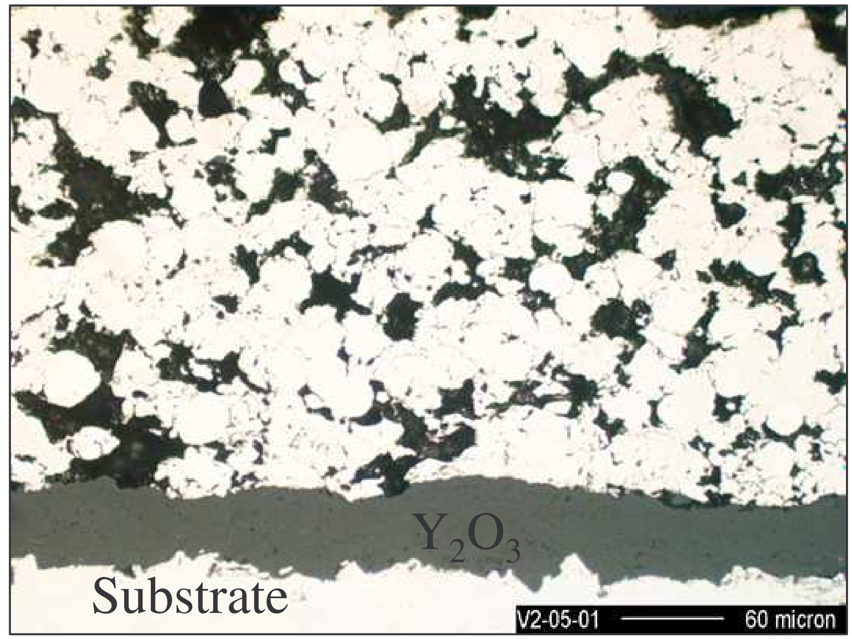


- ~40% porous

The primary difference in the morphology of the pores for the SS and Mo deposits is due to the make of the starting powders.

Porous Deposits on Y_2O_3 Intermediate Layers





- Porous Mo
- Porous SS

Examination of the substrate/Y_2O_3 and Y_2O_3/porous topcoat interfaces reveal no signs of debonding.

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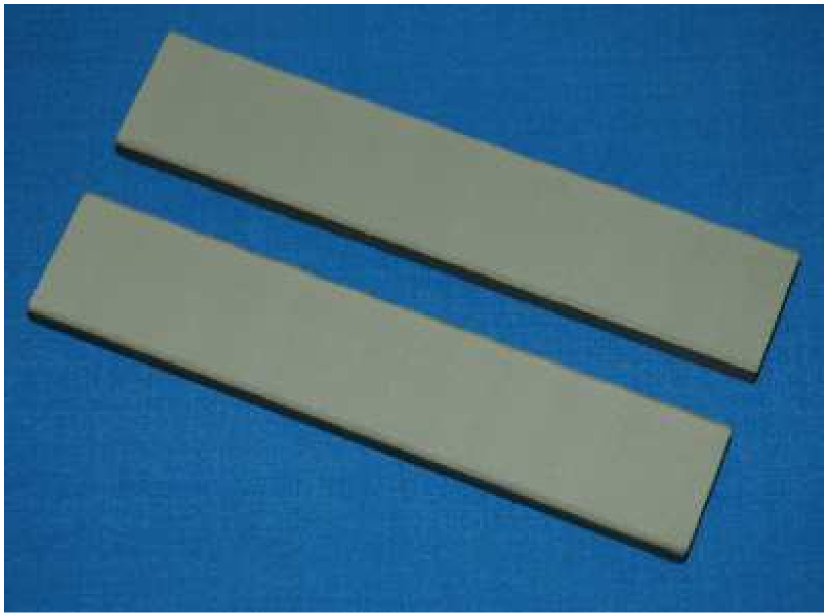
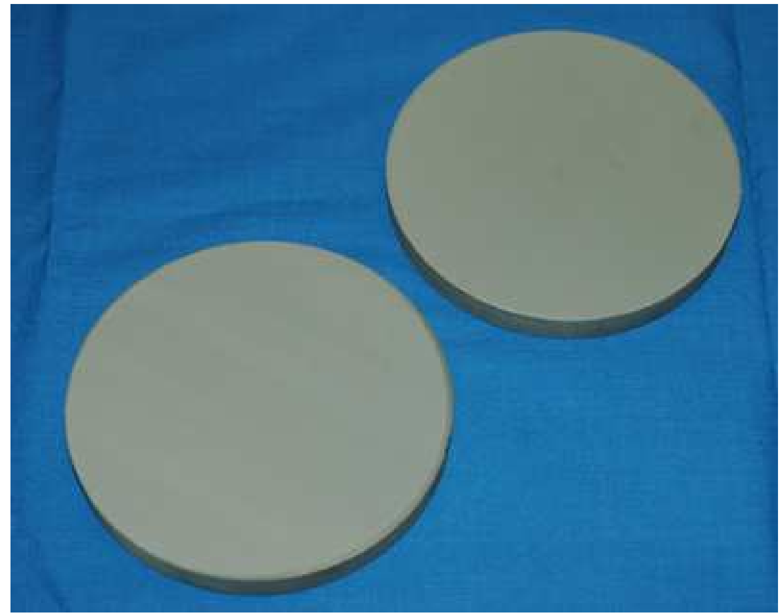
Examples of Samples Produced for Liquid Lithium Testing



• 1” x 5” x 0.2” SS Coupon



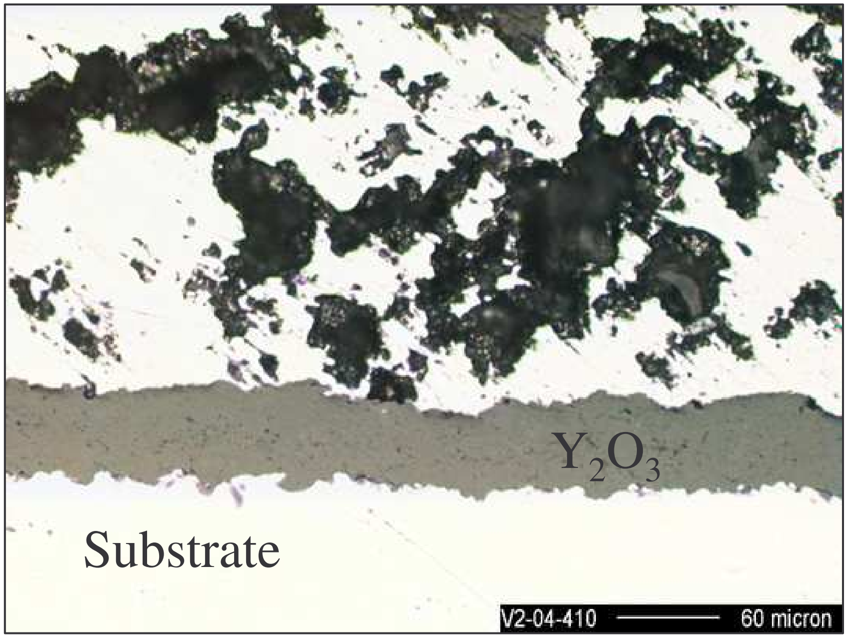
• 5” dia. x 0.5” SS Disk

• Porous Mo and SS deposits were produced with porosity levels ranging between 40-70% porous and thickness from 200-500µm.

• Porous deposits with and without Y_2O_3 intermediate layers were produced.

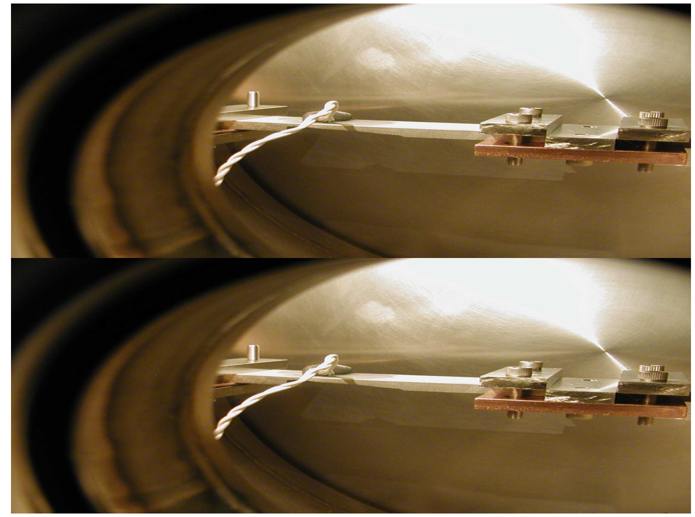
Preliminary Thermal Cycling

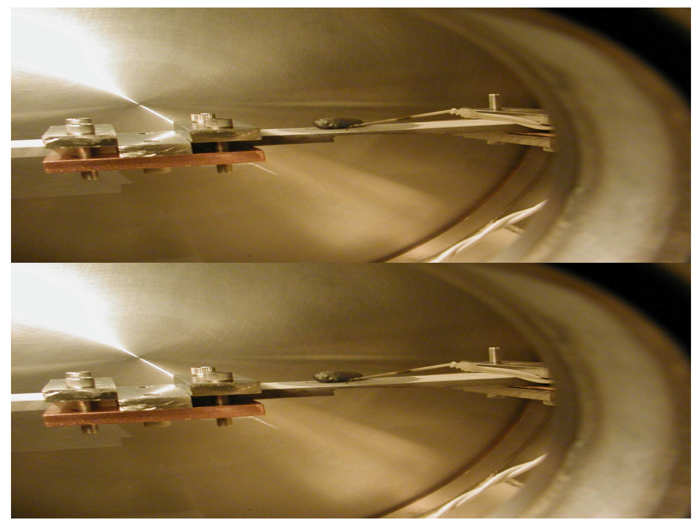
- Samples were heated to 300ºC and held for 1 hour
- Furnace cooled to RT and the cycle repeat a minimum of three times
- Examination reveal no debonding at the interfaces.



Liquid Lithium Testing at PPPL

- Two samples were placed in a vacuum chamber in series for resistive heating.
- A solid piece of lithium was placed on each sample and the system was closed, evacuated and backfilled with Ar for resistive heating.
- Temperature was monitored by a thermocouple on the surface of the sample and by observing the color change in a darkened room.
- For all tests, the temperature was limited to a maximum of 300ºC.
- To produce a thermal gradient in the test samples, a tapered section of material was removed from the bottom of each substrate.





Lithium Wetting of Porous SS Deposit

V2-04-404
SS Substrate
Porous SS Coating: ~375 µm
Porosity: ~40%

V2-05-05
SS Substrate
Porous SS Coating: ~200 µm
Porosity: ~40%

Unlike previously tested smooth surface SS samples that required >500ºC for wetting to occur during resistive heating experiments, the porous SS deposits were wet at <300ºC.

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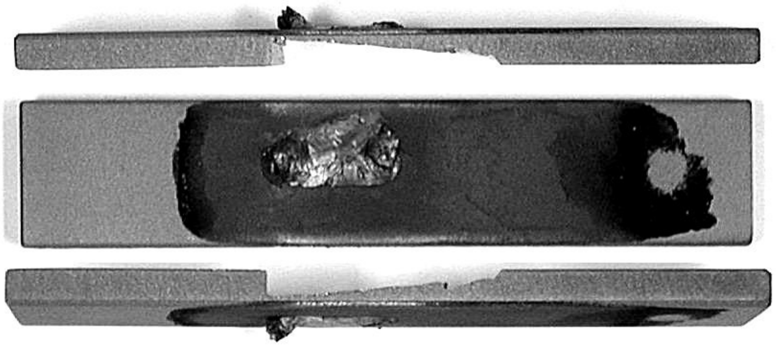
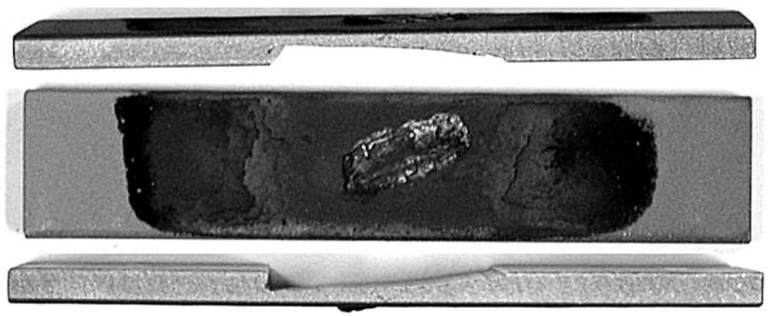
Lithium Wetting of Porous Mo Deposits



V2-04-401
SS Substrate
Porous Mo Coating: ~550 μm
Porosity: ~40%

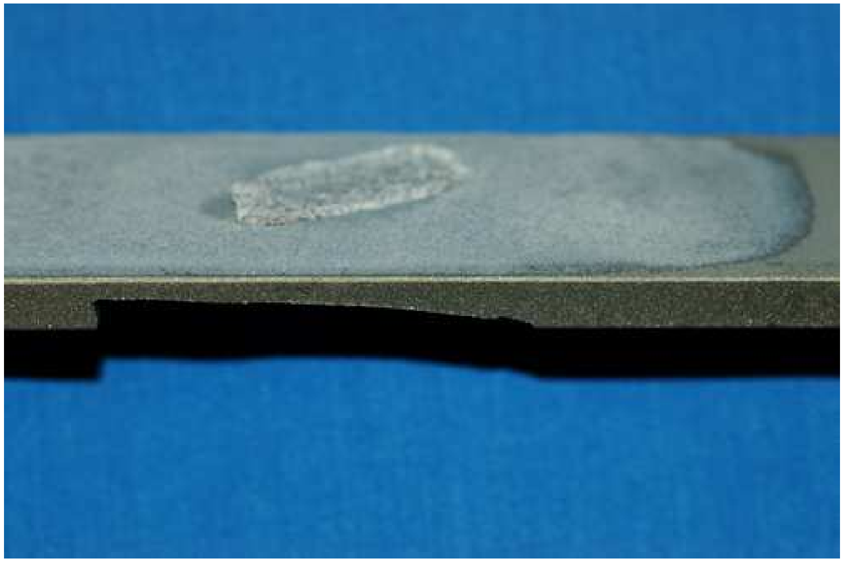


V2-04-412
SS Substrate
Porous Mo Coating: ~450 μm
Porosity: ~70%

- Similar to the porous SS coatings, the porous Mo coatings were wet at <300ºC. Again, previous testing of smooth surface Mo samples required heating to >500ºC for wetting to occur.
- It appeared the higher porosity deposit absorbed more of the liquid lithium even with a slightly lower thickness as compared to the lower porosity deposit.
- Although the tapered section of the substrate did not produce an appreciable thermal gradient driven flow for the samples size tested, the flow of the liquid lithium was constrained to the porous deposit for all tests, i.e., the liquid lithium did not wet the uncoated sides of the SS substrate.

Close-up View of Porous Mo Deposit After Liquid Lithium Testing

- View of coupon where the porous Mo deposit wrapped around the edge of the coupon.



- View of coupon where the porous Mo deposit did not wrap around the edge of the coupon.

Note the liquid lithium flowed over the edge where the coating was present and did not flow over the uncoated edge.

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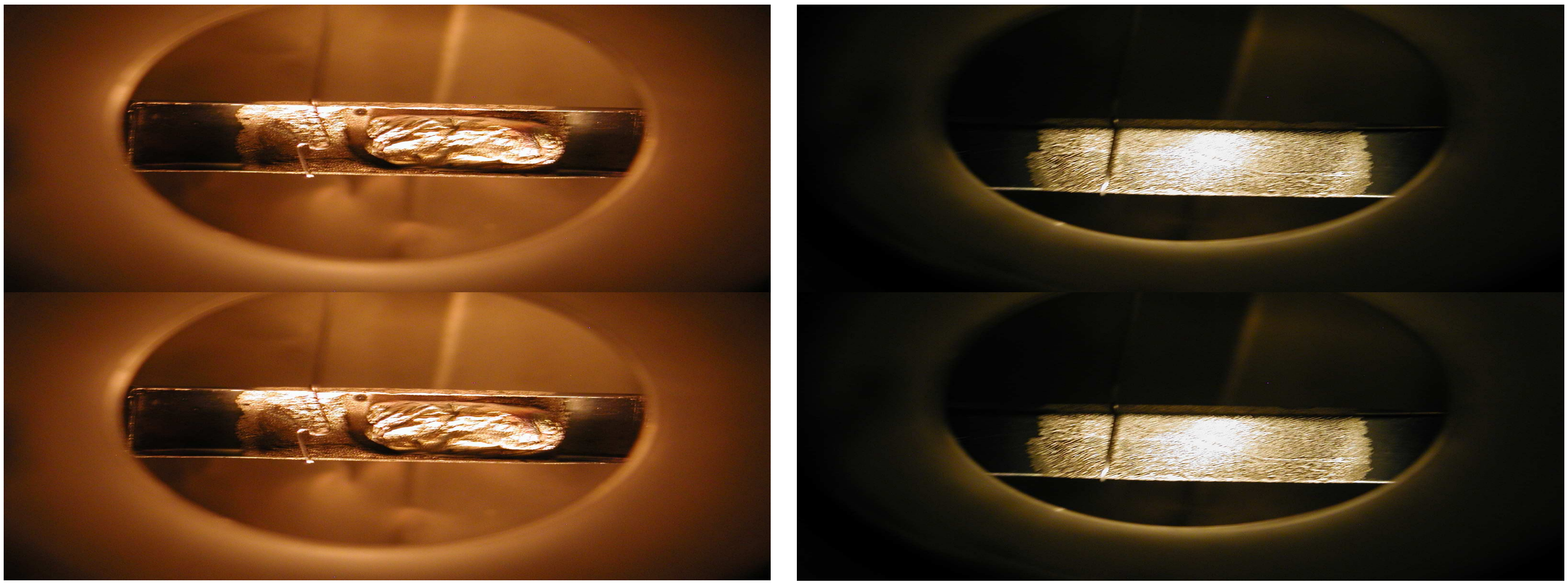
Lithium Wetting of a Smooth Surface Tantalum Boat at PPPL



- Note the molten lithium wet the inside of the Ta boat and flowed up the sides and around to the underside of the boat.

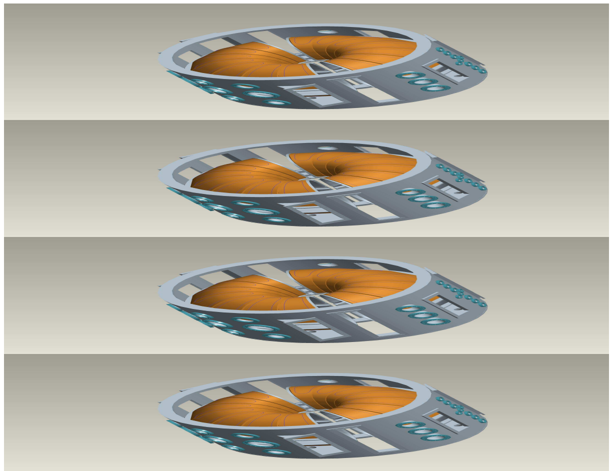
- The use of a porous coating could have controlled lithium flow and restrained wetting to the region of interest, i.e., prevented wetting of unwanted regions such as the underside of the sample.

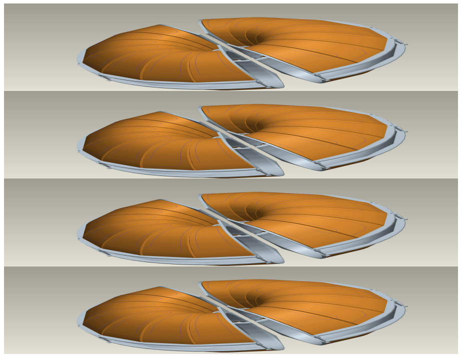
Phase I Summary

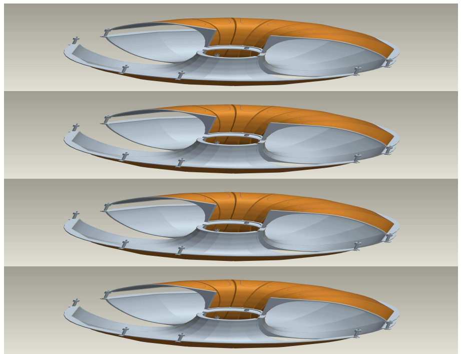
- Plasma spray parameters were developed that enabled the production of engineered surfaces comprised of a high thermal conductivity substrate, with and without Y_2O_3 intermediate insulating layers, and porous metallic topcoat.
- Vital information relating to the effect of different parameters on the resulting deposits were identified.
- Examination of the engineered surfaces' interfaces showed no debonding after fabrication and preliminary thermal cycling.
- Liquid lithium testing at PPPL showed excellent wetting of the porous Mo and porous SS surfaces.
- Previous testing of smooth SS and Mo surfaces required resistive heating to >500ºC before wetting by molten lithium. In contrast, the Phase I Mo and SS porous deposits were wet at temperatures <300ºC.
- During lithium testing, only the coated surfaces of the substrates were wet by the molten lithium. Thus, demonstrating the ability of the plasma spray formed porous deposits to control lithium flow.

Phase II Approach

- Working with PPPL, PPI will optimize the engineered surface concept comprised of a thick lithium film embedded in a porous metallic coating for implementation in LTX.
- A second shell (~1.4m dia) will be constructed and coated with the engineered surface.
- Yield data on stabilization of the thick lithium film by the porous layer in the presence of MHD activity and disruptions
- Suitability of the concept as a PFC
- Allow comparisons to thin films of lithium adhered to a nonporous stainless steel surface which will be first tested in LTX







Phase II Work Plan

- Perform additional molten lithium tests to determine the effect pore size, morphology and composition have on wetting.
- Develop techniques for production of the engineered surfaces on curved surfaces.
- In addition to higher purity Y2O3, evaluate alternative insulating coatings to allow J x B driven flow.
- Determine the robustness of the coatings by performing mechanical and thermal cycle testing.
- Produce subscale components for high heat flux testing in LTX with and without thick lithium films.
- Using the optimize fabrication techniques, coat a full size LTX shell with an engineered surface for testing of the thick lithium film plasma facing concept.

VPS3 Chamber

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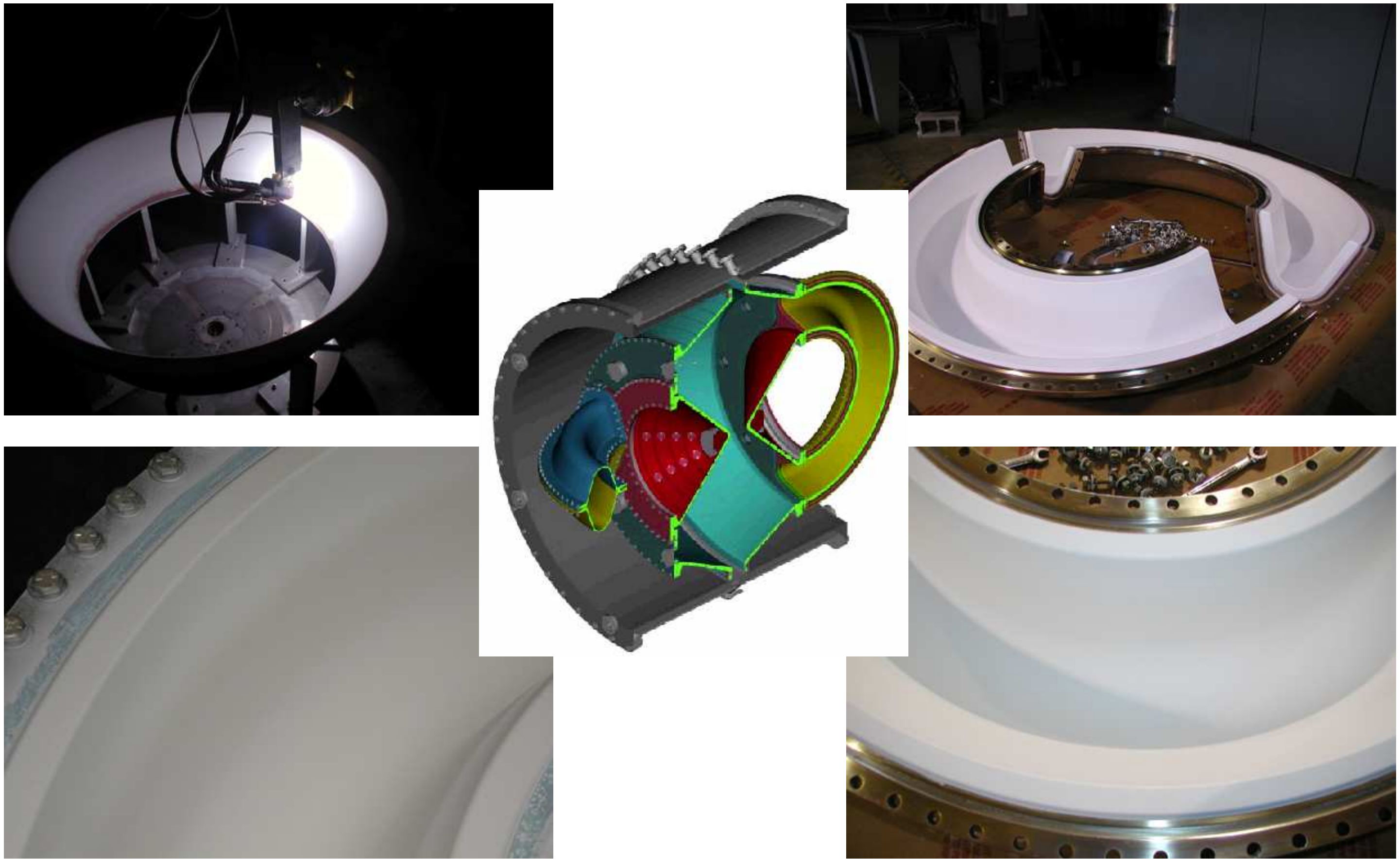
Alumina Coating of HIT Device for University of Washington



Air Plasma Spray formed alumina coatings on HIT components.